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LAWRENCE LIVERMORE NATIONAL LABORATORY

Rugby Hohlraum Campaign on the National Ignition

P. Amendt

September 19, 2013

IFSA Conference
Nara, Japan
September 8, 2013 through September 13, 2013

Rugby Hohlraum Campaign on the National Ignition Facility: Status and Comparison with Modeling

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CEA Design Team

IFSA2013 Nara, Japan
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LLNL-PRES-xxxx

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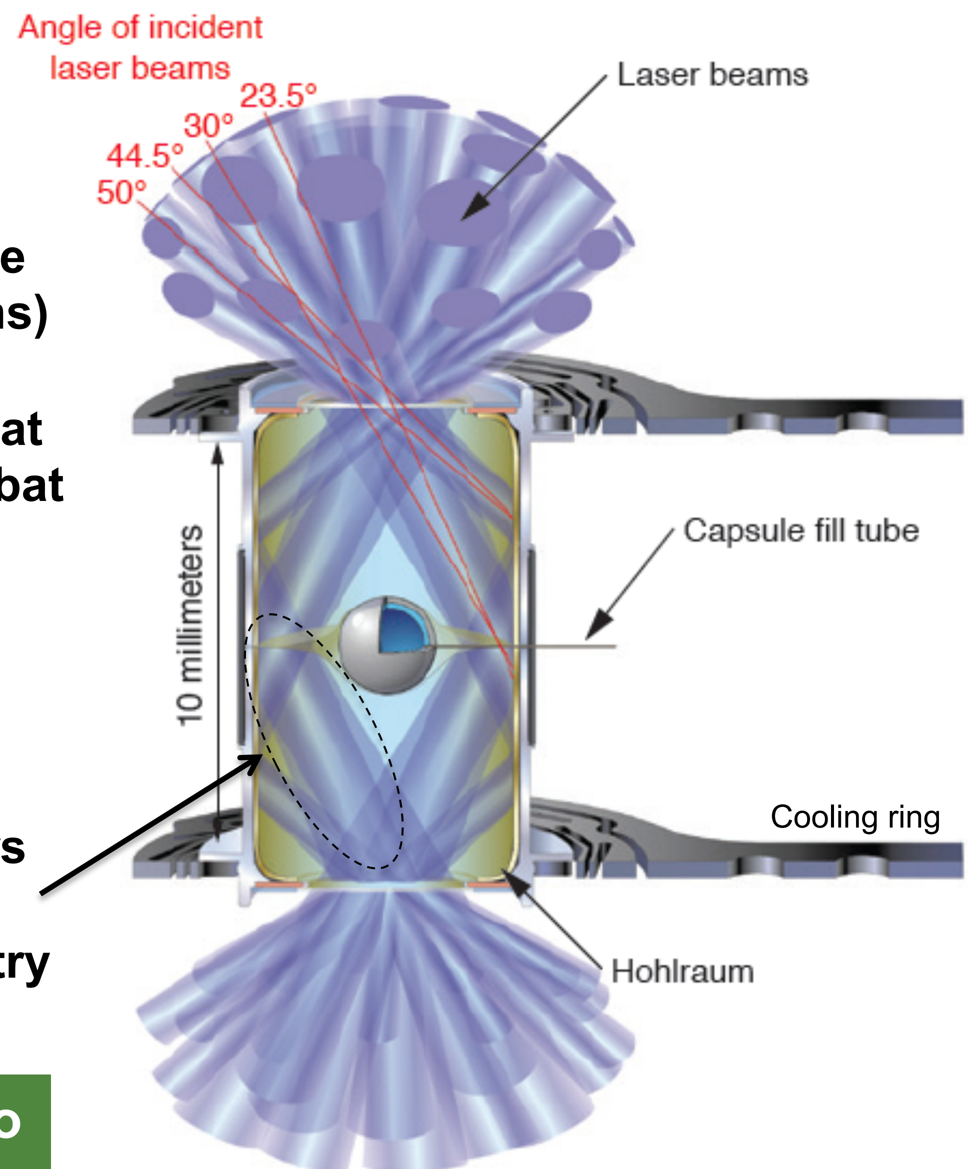
NIC

Ignition campaign on the NIF using hohlraums must achieve high energy coupling and implosion symmetry†

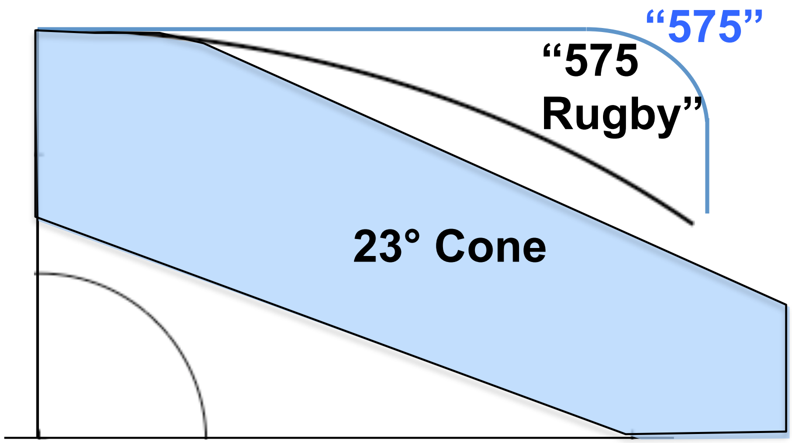
- Incident laser beams generate soft x rays at Au wall
  - T_R~300 eV is needed to drive capsule to high implosion speed (~370 μm/ns)
  - sources of x-ray and electron preheat must be controlled for low fuel adiabat
- X-ray drive on capsule must be highly uniform to ≲1%
  - inner beam propagation in cylinders w/ CH capsules require high Δλ for strong XBET and adequate symmetry



Can hohlraum shape be optimized to reduce need for strong XBET?

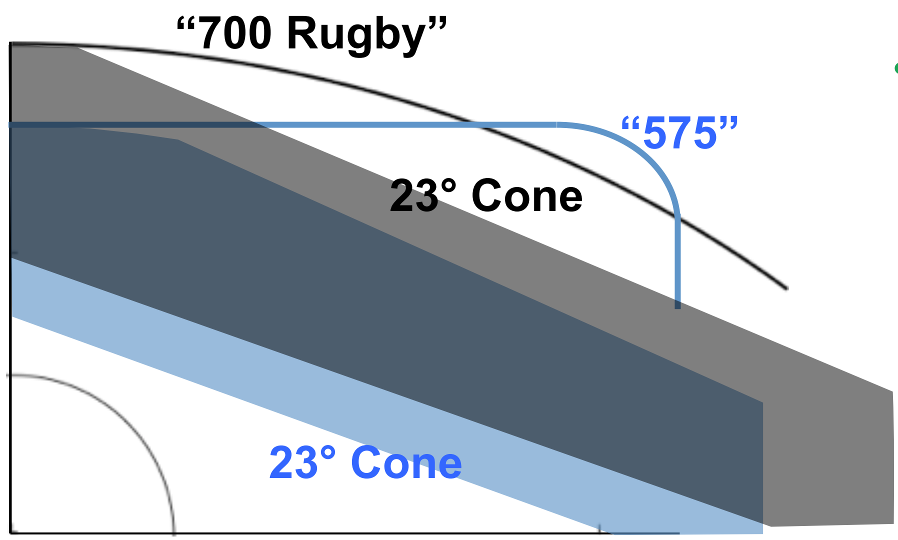
† See plenary talk OP.Mo_A4 by J. Edwards

Potential advantages of a rugby hohlraum on the NIF: (1) Higher drive or (2) improved symmetry and propagation



- Same diameter rugby as "575" cylinder, but ~30% less Au surface area:
  - > 20% higher E_{cap} for same E_L and P_L

or



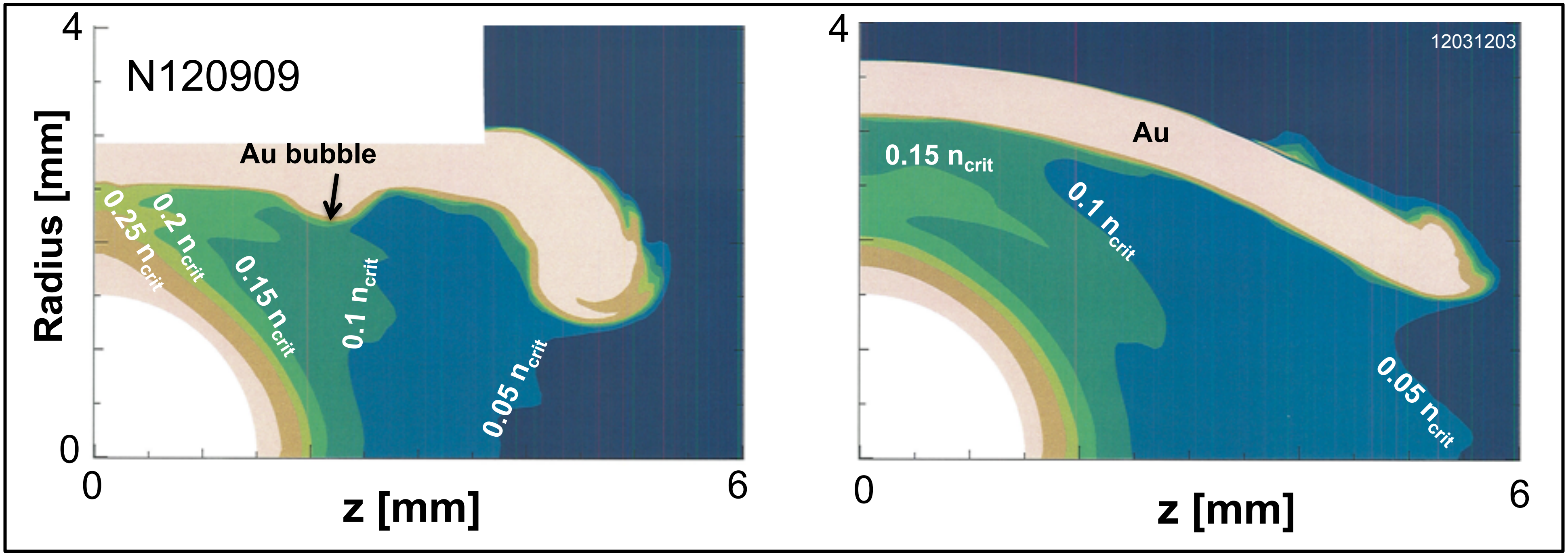
- Same surface area rugby as "575" cylinder, but larger diameter:
  - has higher case-to-capsule ratio for improved flux symmetry
  - greater beam clearances, lower density => better beam propagation

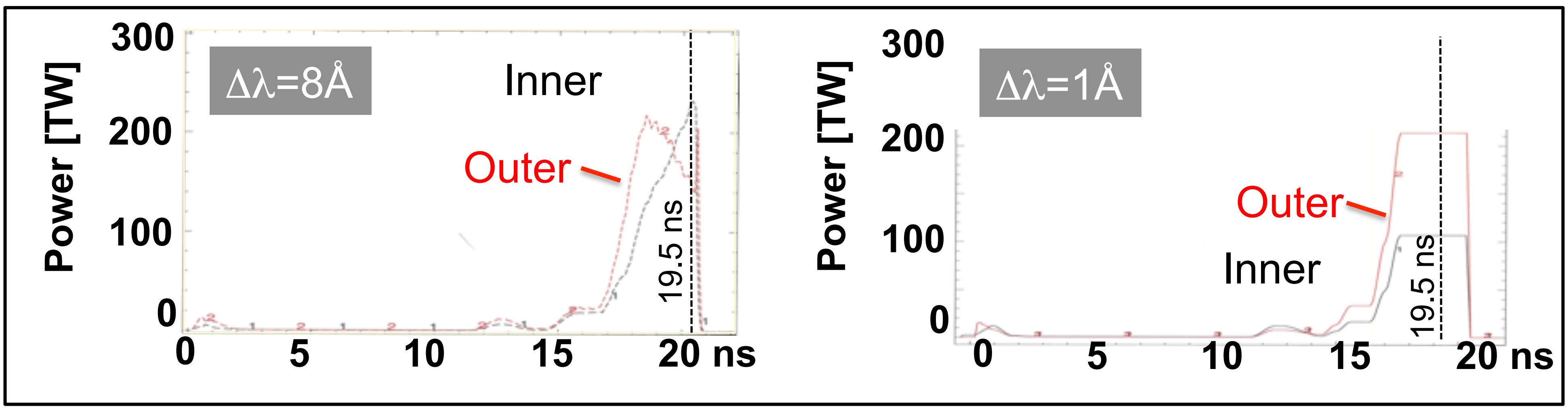
"700 rugby" was chosen to facilitate beam propagation and achieve good symmetry without use of large $\Delta\lambda$ for XBET

BENEFITS

"700 Rugby" preshot modeling showed lower plasma density and robust inner beam propagation at 19.5 ns

- Initial rugby He fill is 1.20 mg/cc; 0.96 mg/cc for companion cylinder

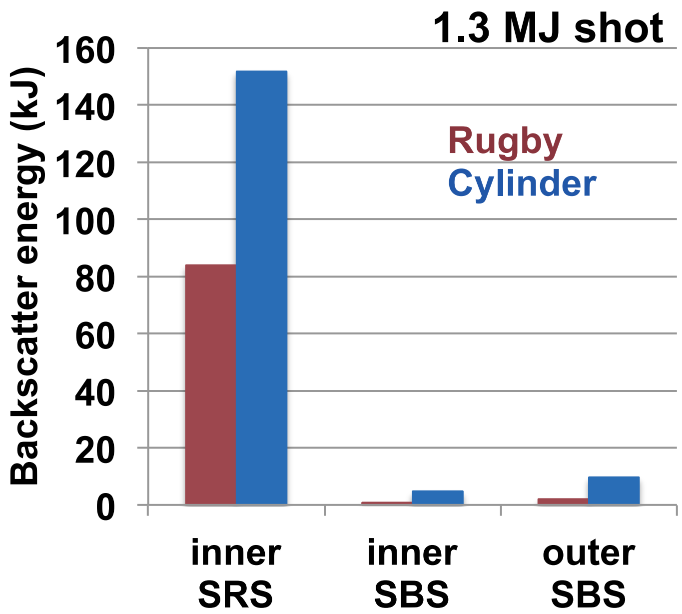




SUMMARY

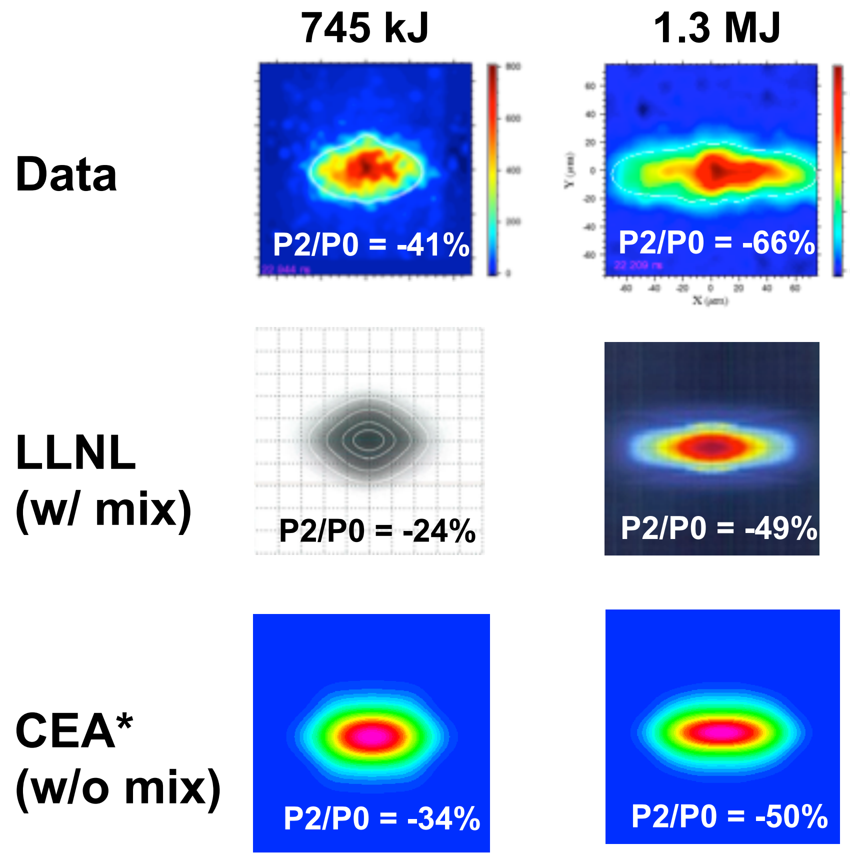
First rugby shots showed improved energy coupling, but significantly “pancaked” low-foot CH implosions

Rugby: 93% coupling
Cylinder: 87% coupling



Rugby backscatter dominated by inner cone SRS

Implosion shape consistent with LLNL calc’s only with Au-He mix



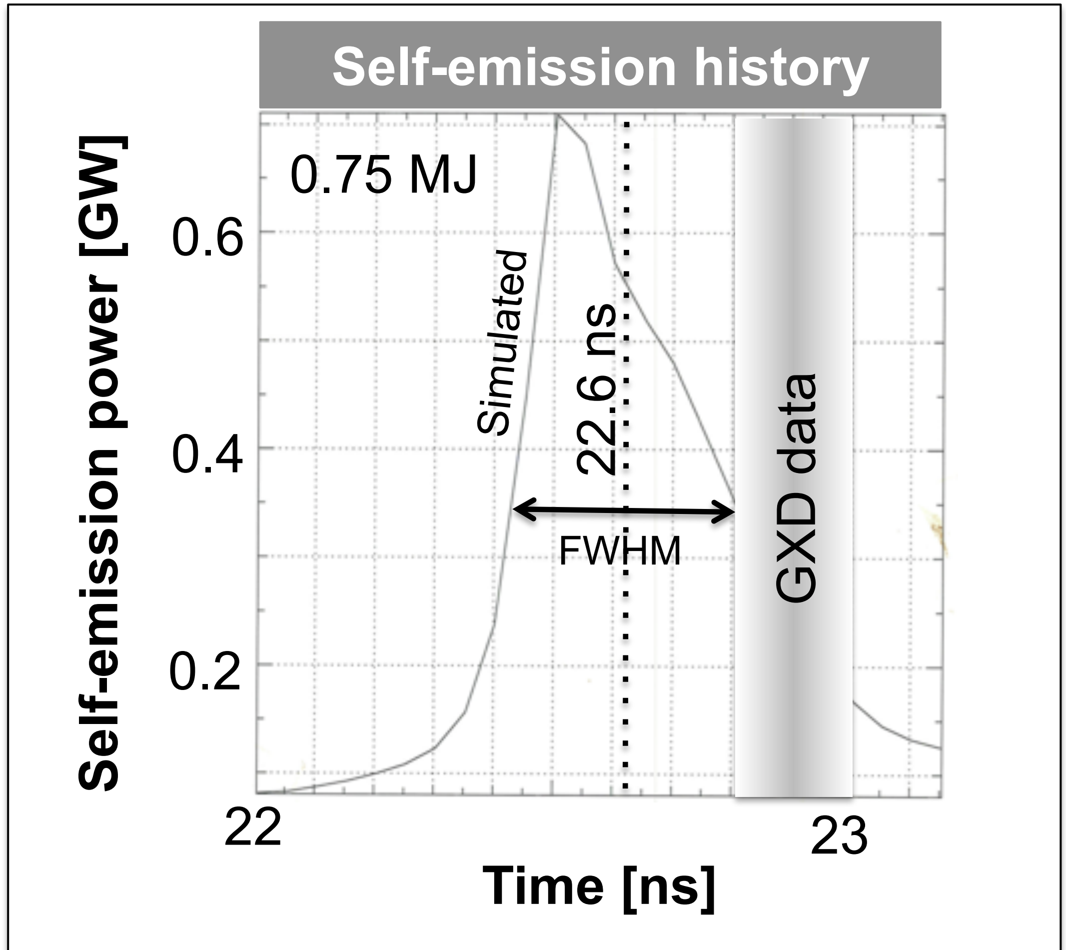
* P. Gauthier, J.-P. Leidinger

Rugby hohlraum platform provides potential for improving coupling efficiency and optimizing symmetry without high XBET

BANGTIME (N130318)

Simulated x-ray bang time is ~22.6 ns, or nearly 300 ps earlier than gated x-ray detector (GXD)

- No multipliers were used in 2-D hohlraum simulations
  - fully Lagrangian while laser is on, highly resolved zoning
  - nonlocal electron transport is implemented
  - used measured back-scatter SRS, SBS histories
  - 1Å wavelength separation (weak transfer of outer cone energy to inners by design)



Rugby drive reduction is ~1/2x inferred in cylinders

SYMMETRY

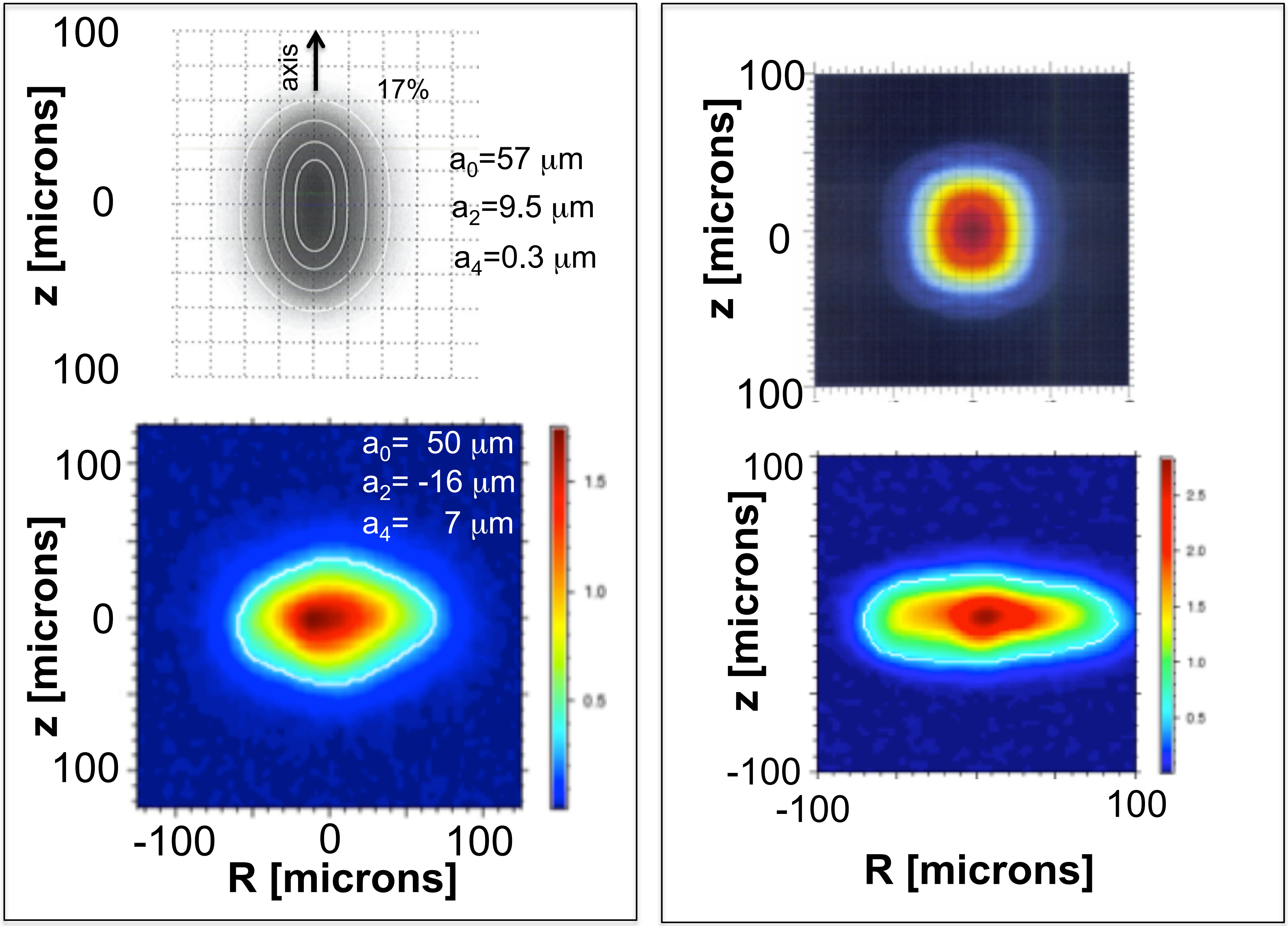
Rugby data show surprising differences with LLNL simulations for capsule implosion asymmetry

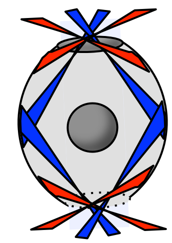
0.75 MJ

1.3 MJ

SIMULATIONS

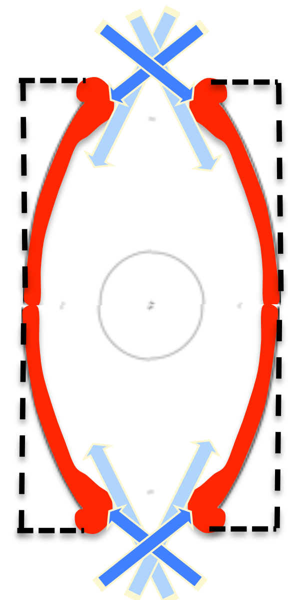
MEASUREMENTS





Large differences between data and LLNL modeling of x-ray imploded core images call for explanations

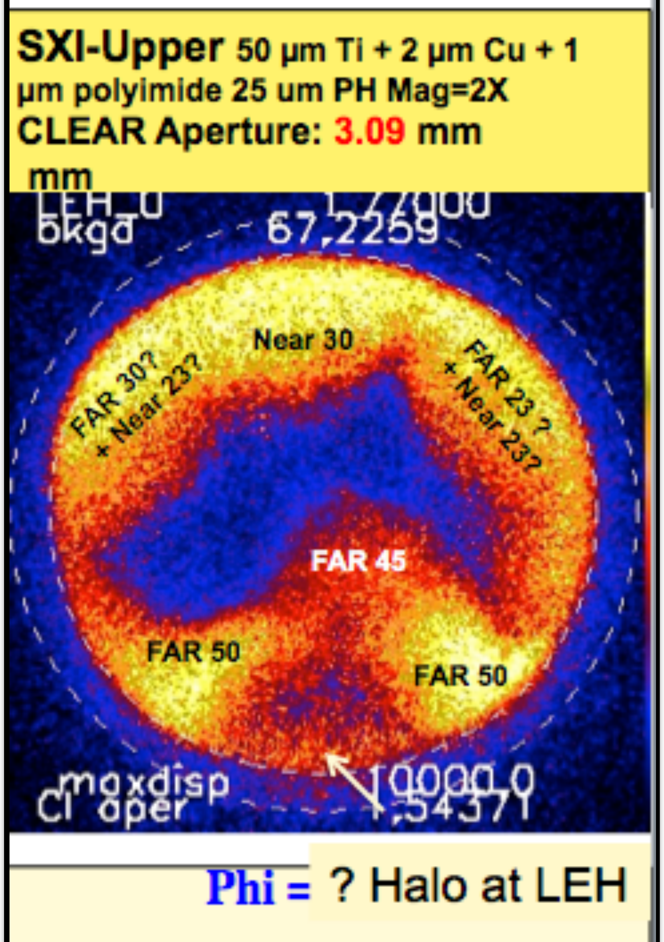
- More Au hohlraum wall motion than (LLNL) simulated is strong candidate
  - LLNL non-LTE model is based on XSN
  - CEA non-LTE model is based on tables (Busquet)
- Rugby shape amplifies effect of impaired inner beam propagation compared with cylinders
  - He/Au mix from Rayleigh-Taylor (RT) instability?
  - Au infiltration of He from plasma kinetics?
  - Hydrocoupling? Reversed XBET? Larger 3D bubbles? Refraction?



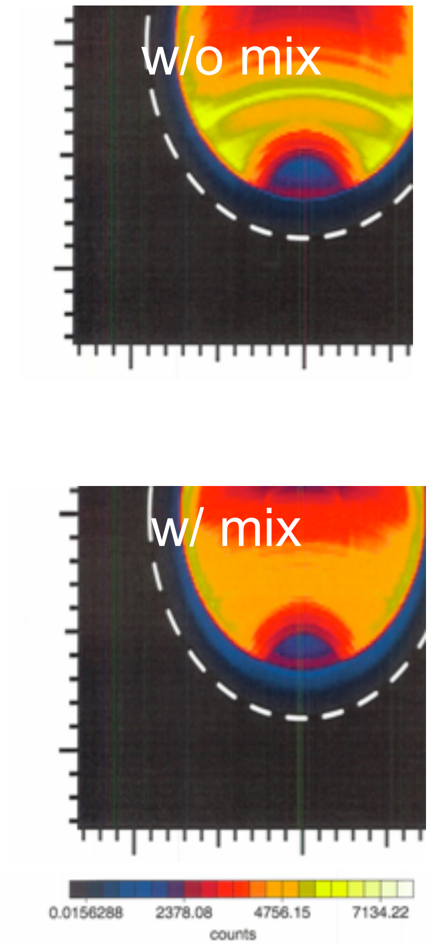
Dramatic rugby result demands explanation that could even impact understanding of cylinders

3-5 keV x-ray images of LEH show evidence of inner beam clipping not seen in simulations, i.e., a “halo”

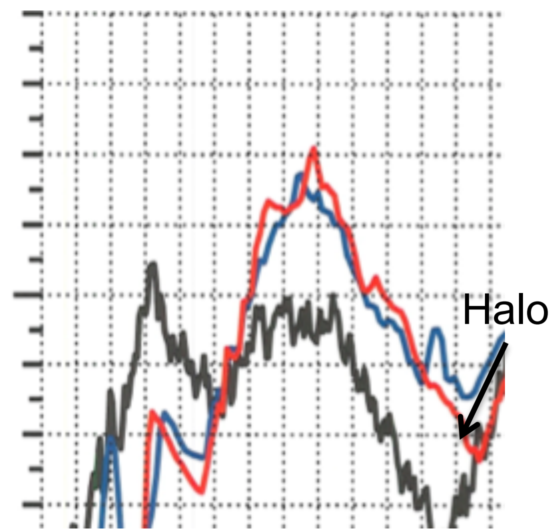
DATA



2D SIMULATIONS



LINEOUTS



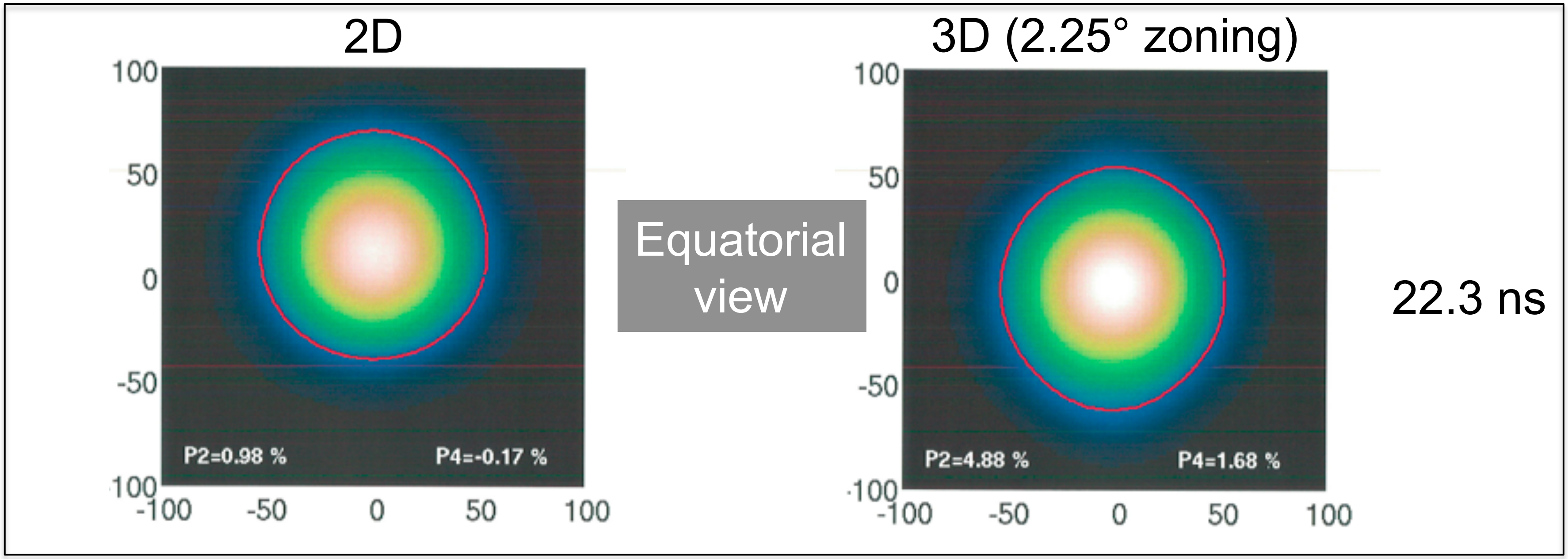
Red: no mix

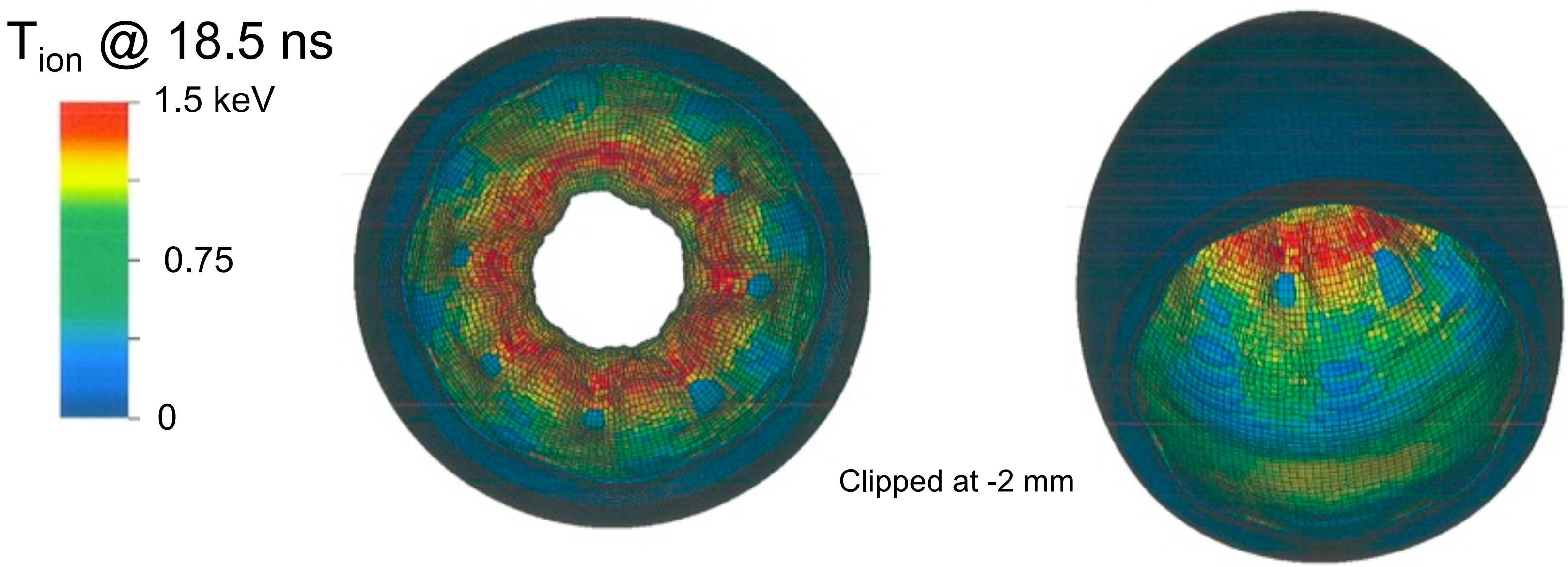
Blue: with mix

Black: data

0.75 MJ shot

3D simulations show only modest outer cone “bubbles” - too small to hinder inner cone propagation at late time

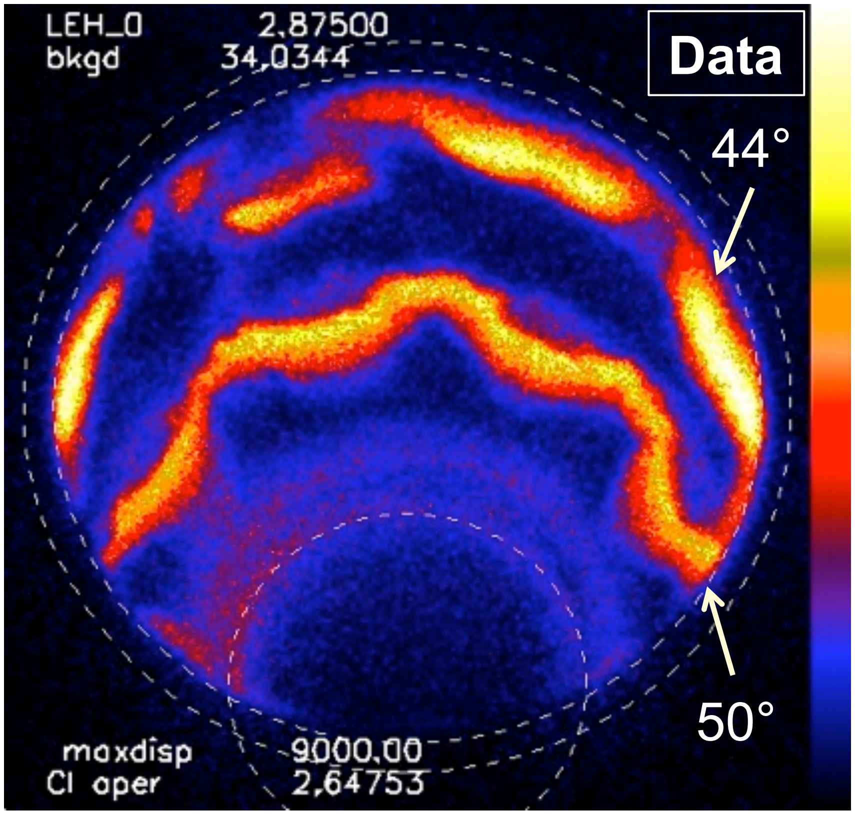


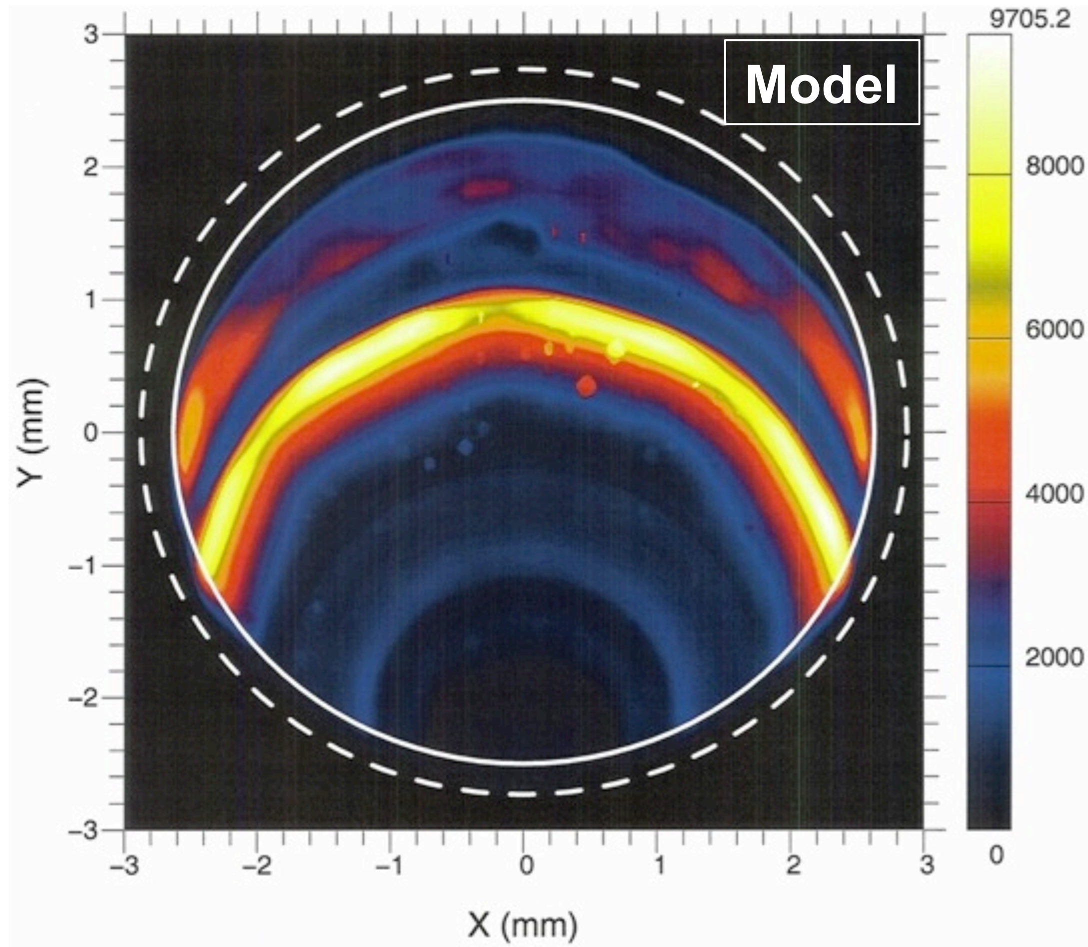


However, hard (3-5 keV) x-ray data show clear wiggles in the outer-cone spots that are absent in 3-D HYDRA*

Static X-Ray Imager (SXI)

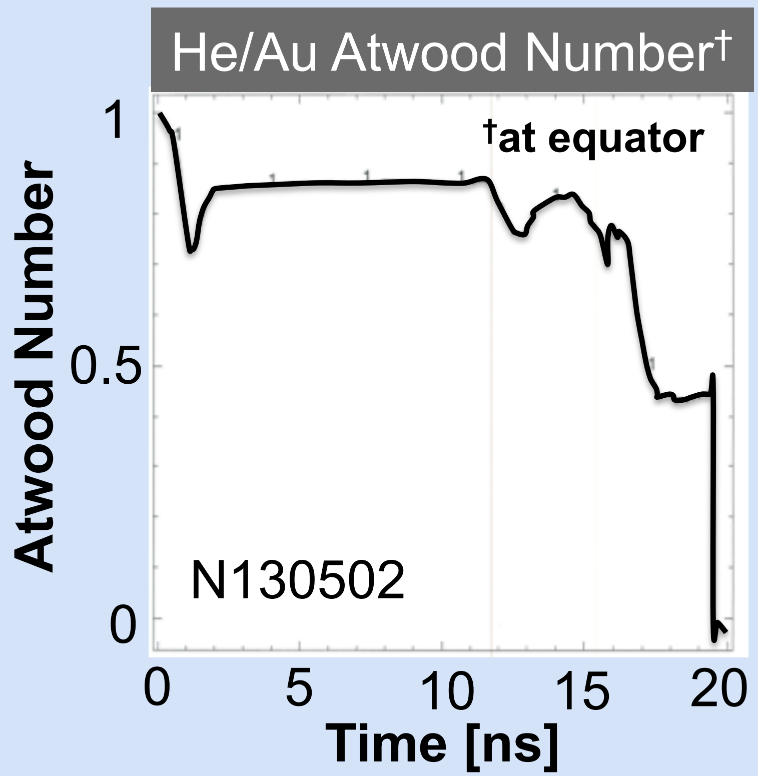
*Courtesy of Nathan Meezan

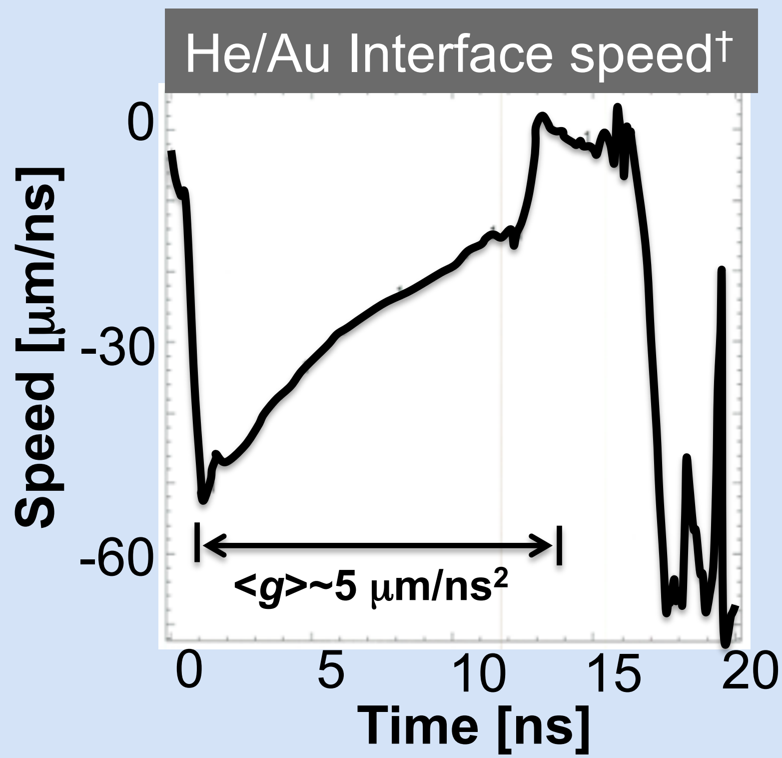




HYDRA simulation does not show observed large "gold bubble" for 50° quads, which could potentially hinder inner cone propagation in rugby hohlraums

Au could infiltrate He during drive trough via hydro-instability, e.g., Rayleigh-Taylor



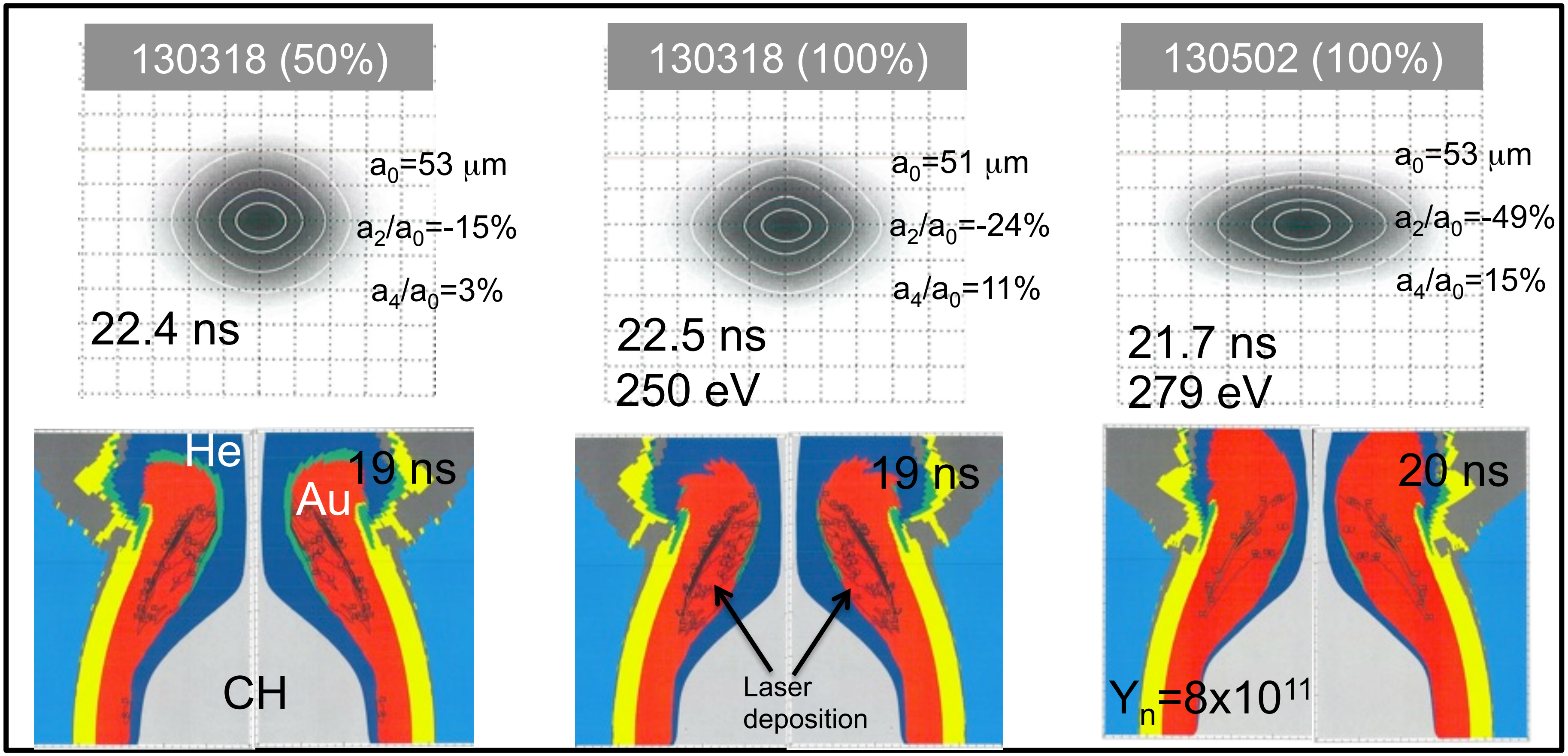


- Early time laser speckle can seed instability on speckle width scale: $x_0=2f\lambda$
- Gain-length product $\sim \sqrt{At \cdot <g> \cdot 2\pi / x_0} \cdot t \cong 16$ => Nonlinear saturation
- Youngs-type nonlinear mix model $(\sim \alpha_s At \cdot gt^2)$ gives mix width >100 μm

NIC

Application of mix model shows impeded inner cone propagation in Au/He mix region, leading to asymmetry

- **Apply fall-line analysis in 2D integrated hohlraum simulations, using 50%, 100% penetration fraction from classical fluid interface to fall line**

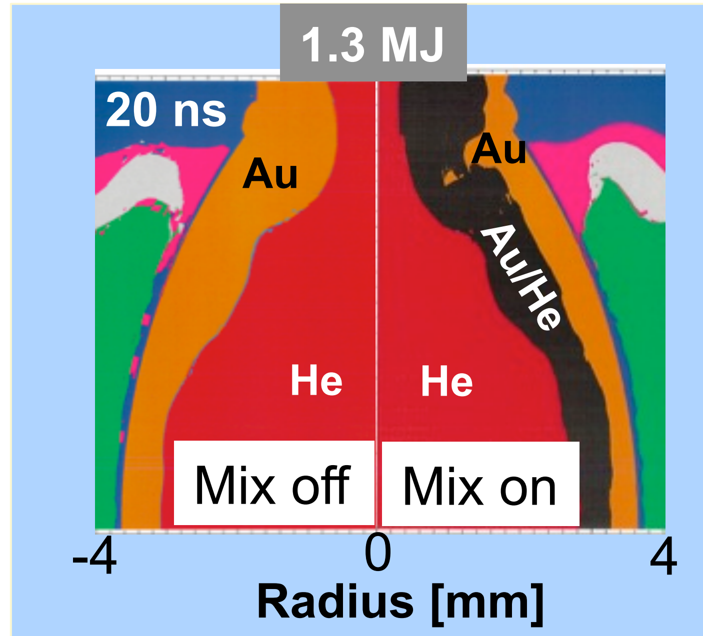


OBSERVED:	22.9 ns 251 eV -------	a_0=50 μm a_2/a_0=-32% a_4/a_0=14%	22.4 ns 283 eV Y_n=1.8x10^{11}	a_0=49 μm a_2/a_0=-71% a_4/a_0=39%

FUTURE

Priority is to understand dramatic asymmetry, then apply remedial measures for control and testing

- Unexpected asymmetry in new platform requires understanding
  - high core asymmetry is consistent with (200-300 μm) more wall motion
  - inferred higher wall motion could be present in cylinders, affecting required degree of XBET

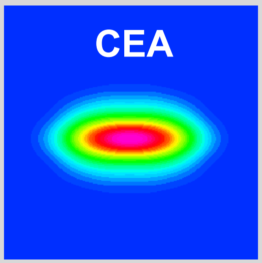


- Higher inferred wall motion requires cures:
  - repoint beams? ✔
  - turn OFF problematic 23° beams?
  - larger LEHs, smaller phase plates, higher foot, i.e., more gas fill?
  - split quads in azimuth to reduce risk of 3D “bubble” growth? ✔
- Strong collaboration with CEA scientists will lend independent voice on resolving relative role of NLTE and mix physics

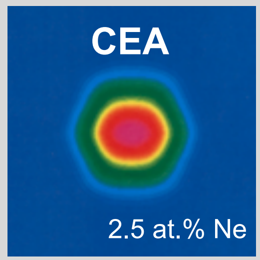
FUTURE

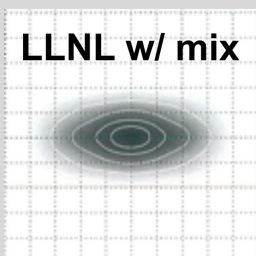
Simulated rugby symmetry is sensitive to degree of wall motion in vicinity of outer cones

CEA/LLNL calculations show that repointing outer cone improves symmetry

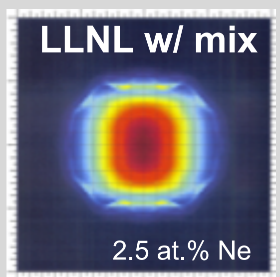


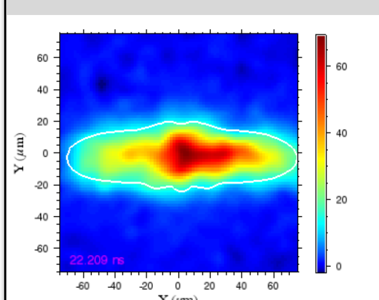
Repoint outers by 500 um





Repoint outers by 400 um

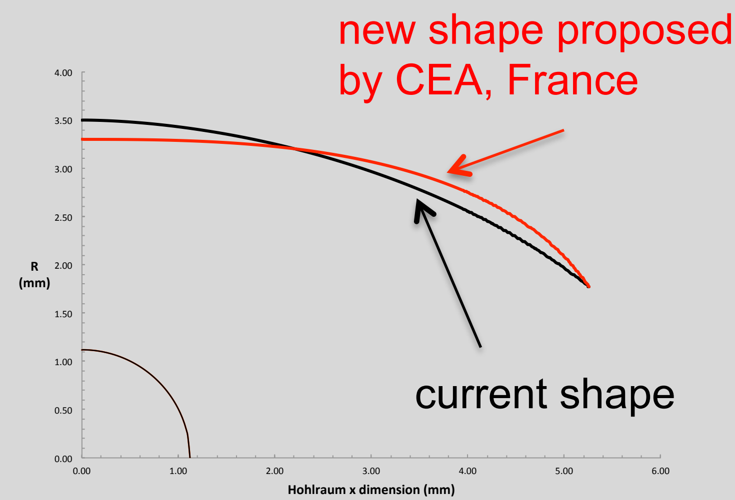




Repoint outers

Expt Proposed FY14

CEA proposes reshaping rugby to reduce sensitivity to modeling



Hohlraum wall further away from axis but same wall area maintained

SUMMARY

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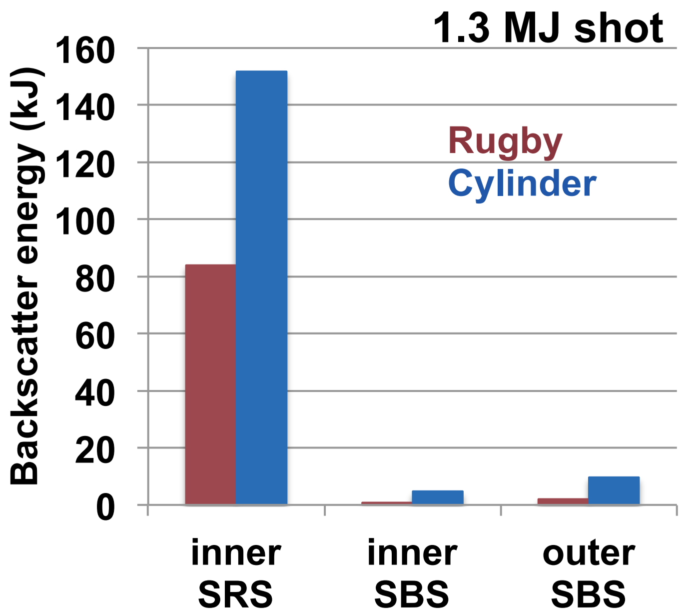

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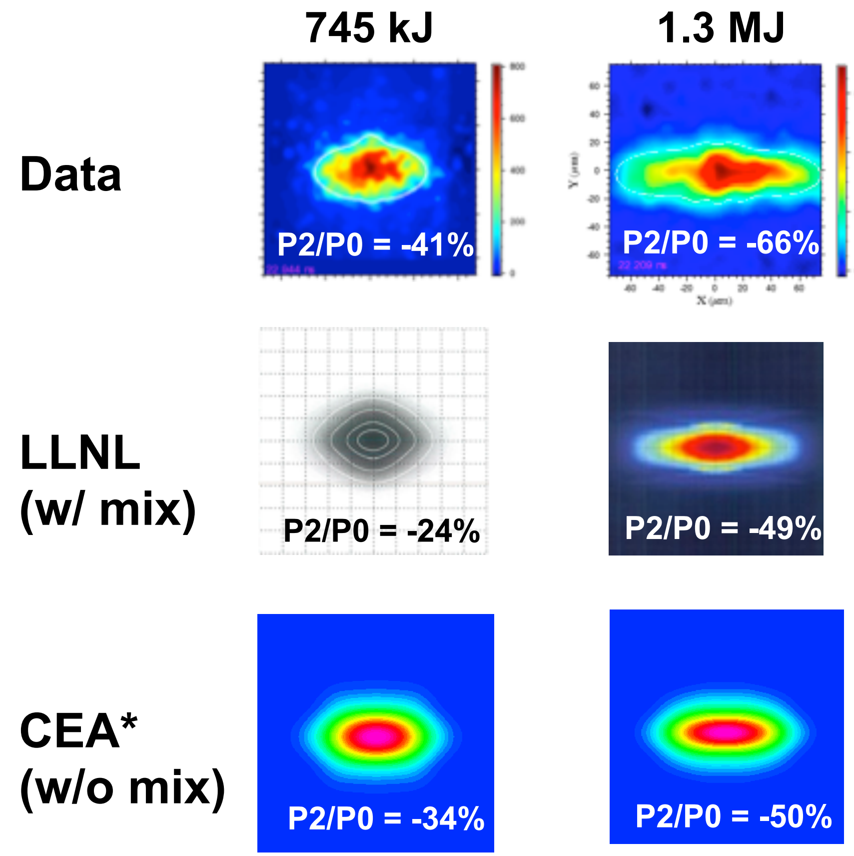
Implosion shape consistent with LLNL calc’s only with Au-He mix



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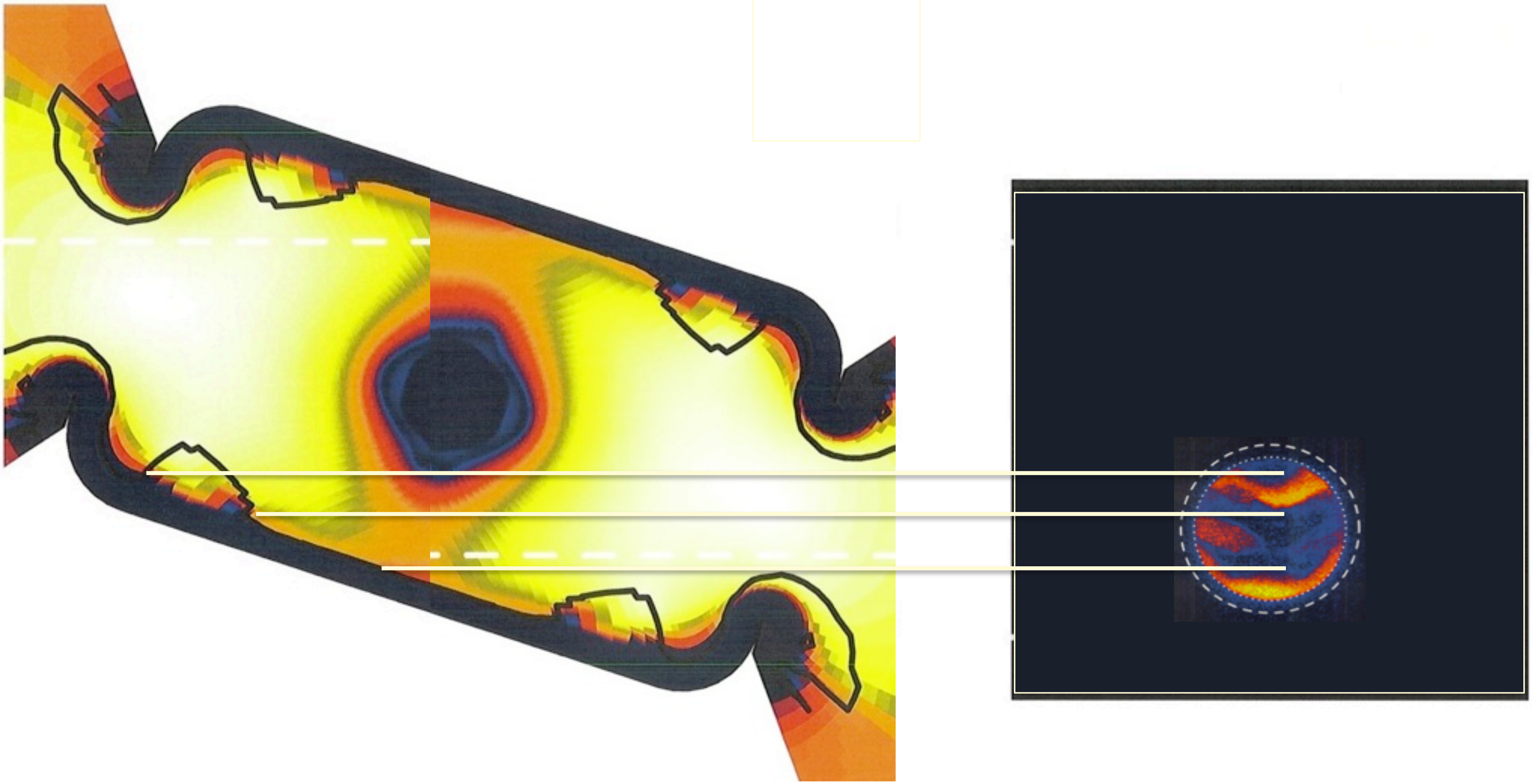
Rugby hohlraum platform provides potential for improving coupling efficiency and optimizing symmetry without high XBET


NIC

In a typical hohlraum, a small fraction of the illuminated wall is visible by x-ray diagnostics

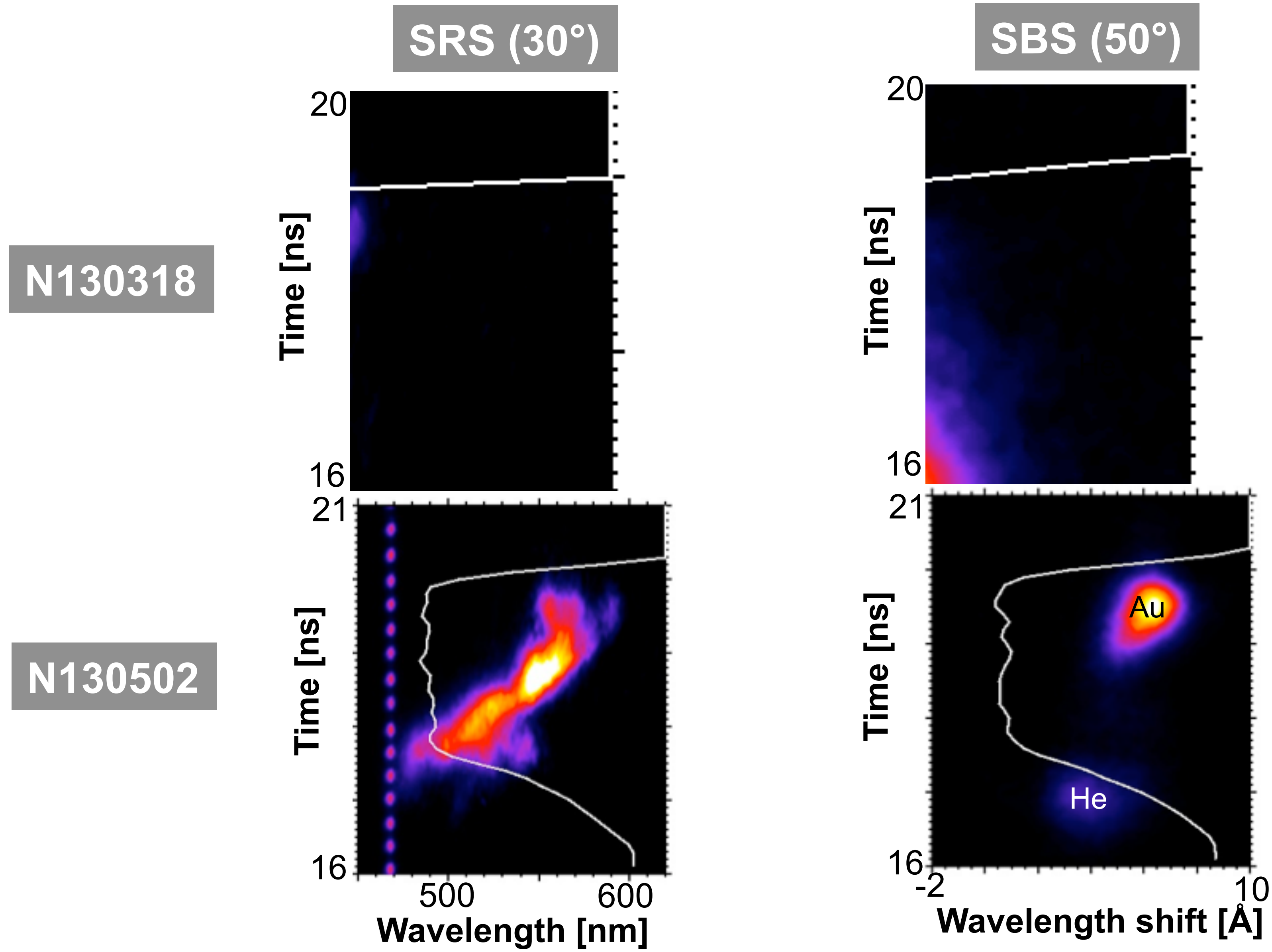
T_e profiles and gold/gas boundary for 2-sided hohlraum

Static x-ray imager (SXI-L) data through LEH



BACKSCATTER

SBS levels remained low at full energy; SRS roughly scaled with laser energy



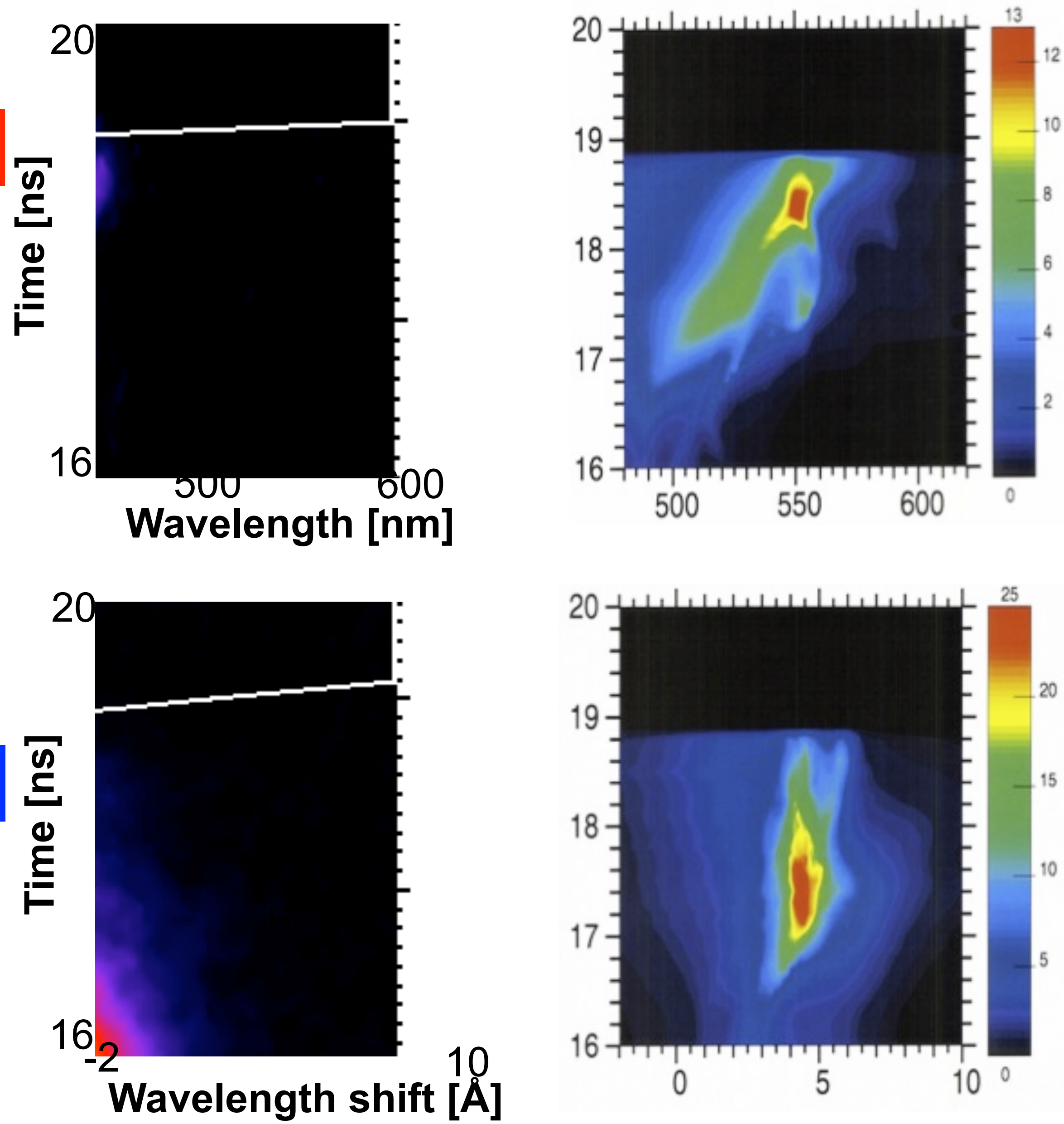
BACKSCATTER

N130318

Gain spectra from simulations that match N130318 symmetry compare favorably with experimental spectra

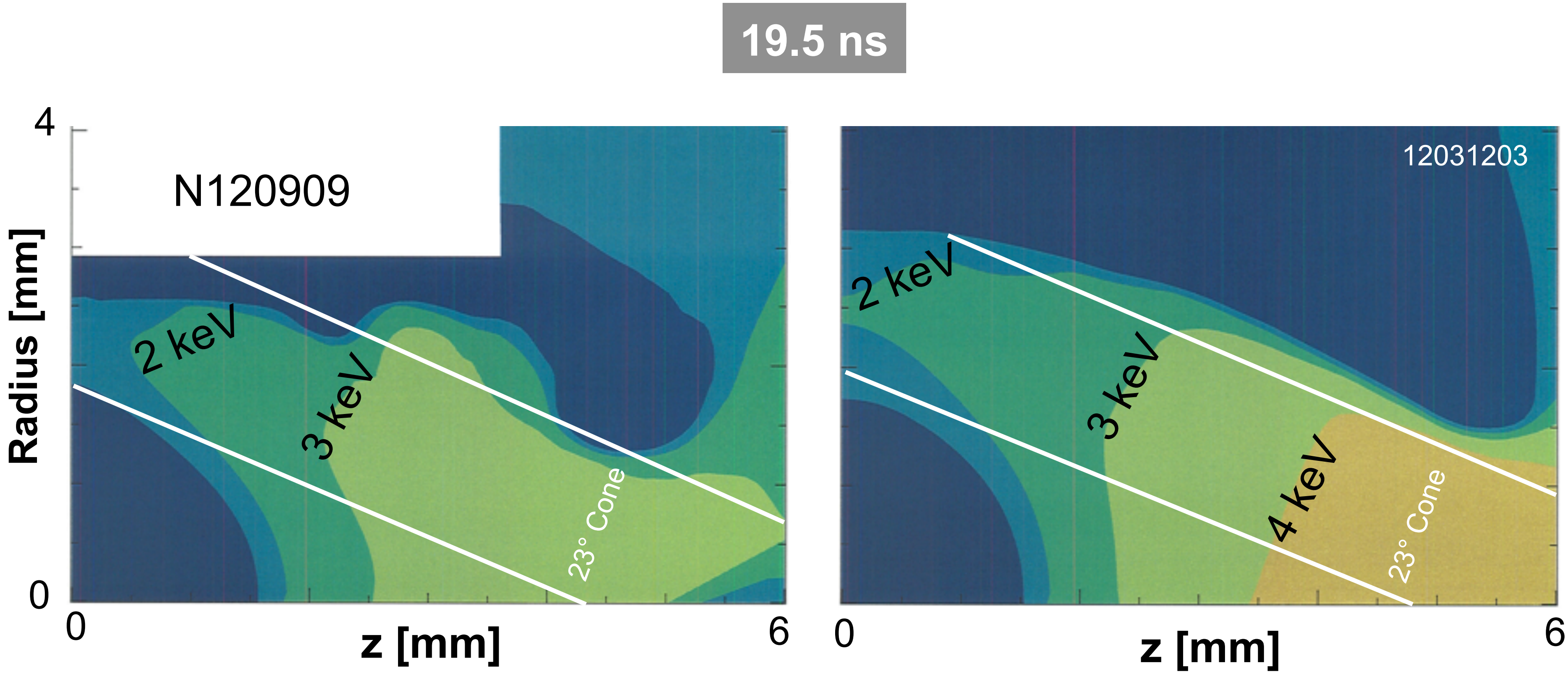
SRS (30°)

SBS (50°)



Preshot Rugby 700 simulations showed higher electron temperature and potential for reduced SRS backscatter

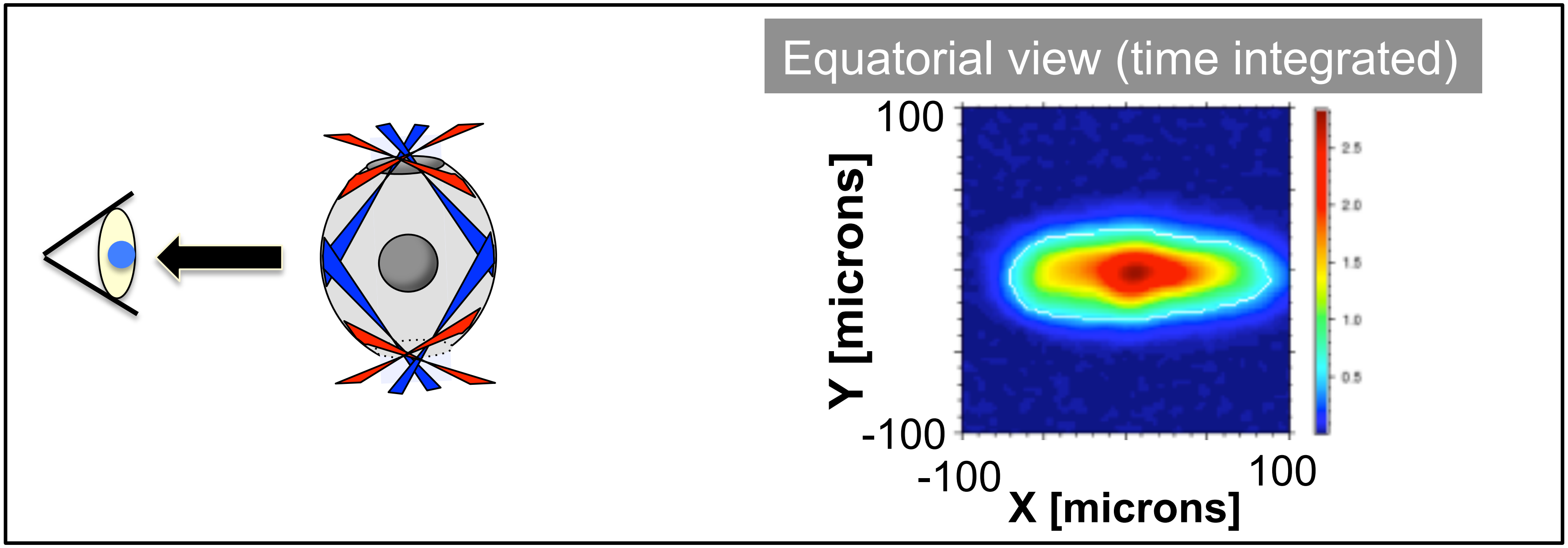
- Initial rugby He fill density is 1.20 mg/cc; 0.96 mg/cc for companion cylinder

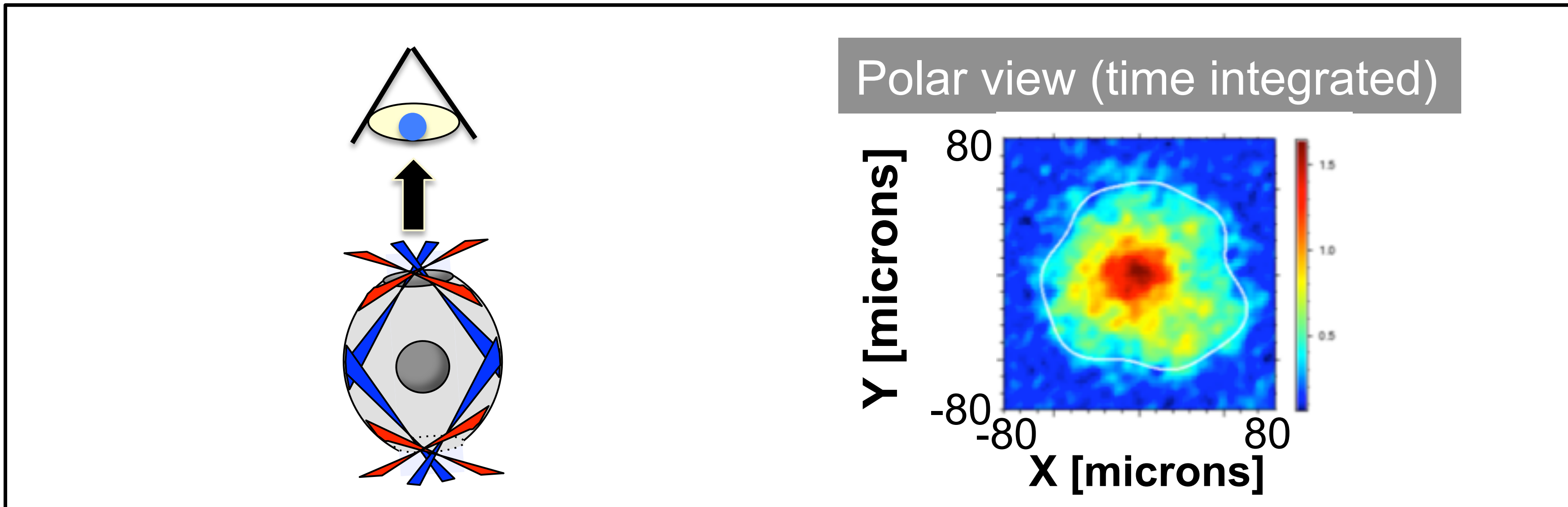


SYMMETRY (2nd)

Second rugby shot showed extreme core asymmetry, in marked constrast to pre-shot simulations (~round)

Courtesy of N. Izumi, S. Khan and T. Ma





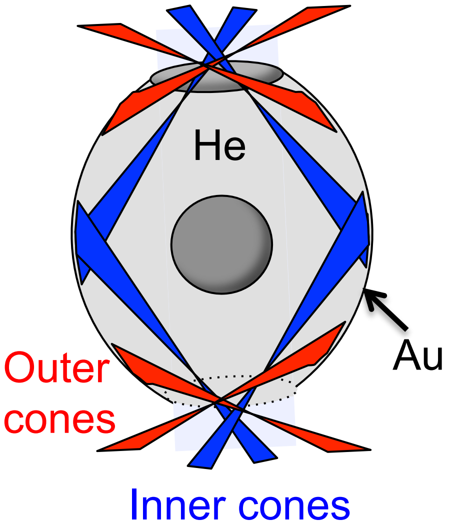
SUMMARY (1^{st})

First rugby shot was fielded on March 18, showing good coupling but marginal symmetry at 750 kJ

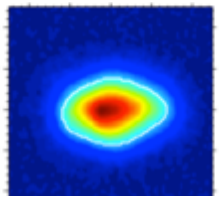
- Hohlraum coupling efficiency was high at ~94.5%
  - inner cone backscatter was dominant (SRS)
  - SBS levels were in the noise on all beams
- x-ray bang time was ~300-500 ps late compared with simulations
  - GXD may have missed brightest core image
- Core image was “pancaked”, in contrast to simulations
  - cool hohlraum (low T_e) driven at ~700 kJ may have thwarted inner beam propagation
- Measured Au M-band fraction (pre-heat) was low (~12%), as predicted (~10%)

First two NIF rugby hohlraum shots gave low backscatter but significantly asymmetric implosions

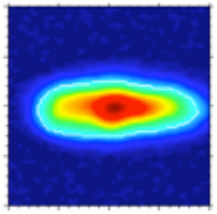
- **Overview of rugby hohlraum properties**



- **March 18 shot (750 kJ)**



- **May 2 shot (1300 kJ)**



- **Potential Au-He hohlraum “mix” scenario for explaining data trends**

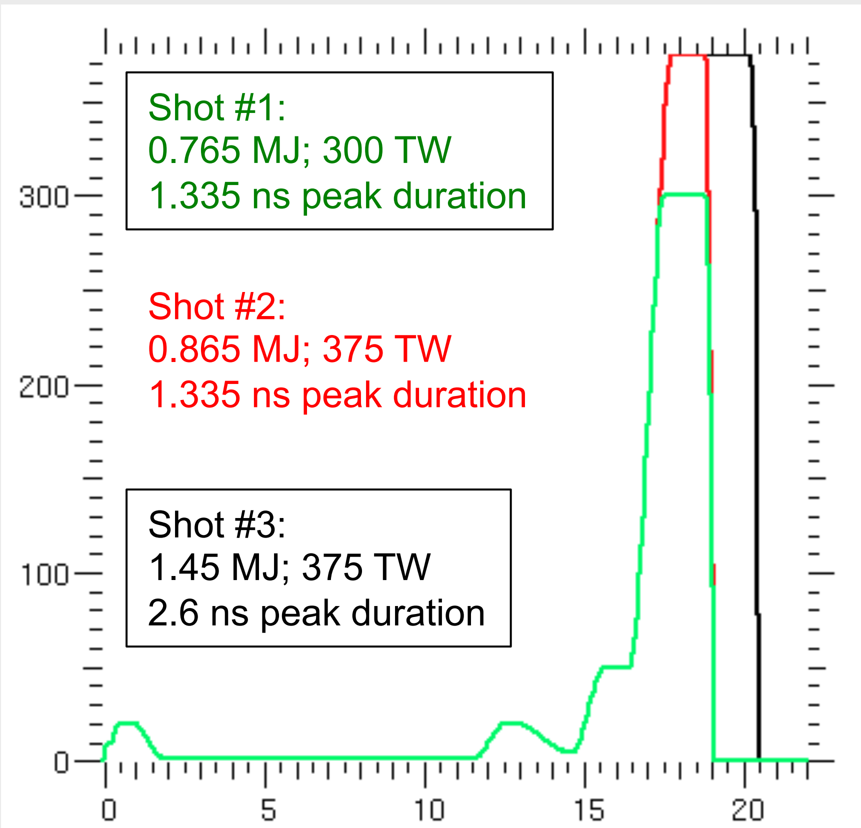
- **Options and Future**

Rugby hohlraum platform provides potential for improving coupling efficiency and optimizing symmetry without high XBET

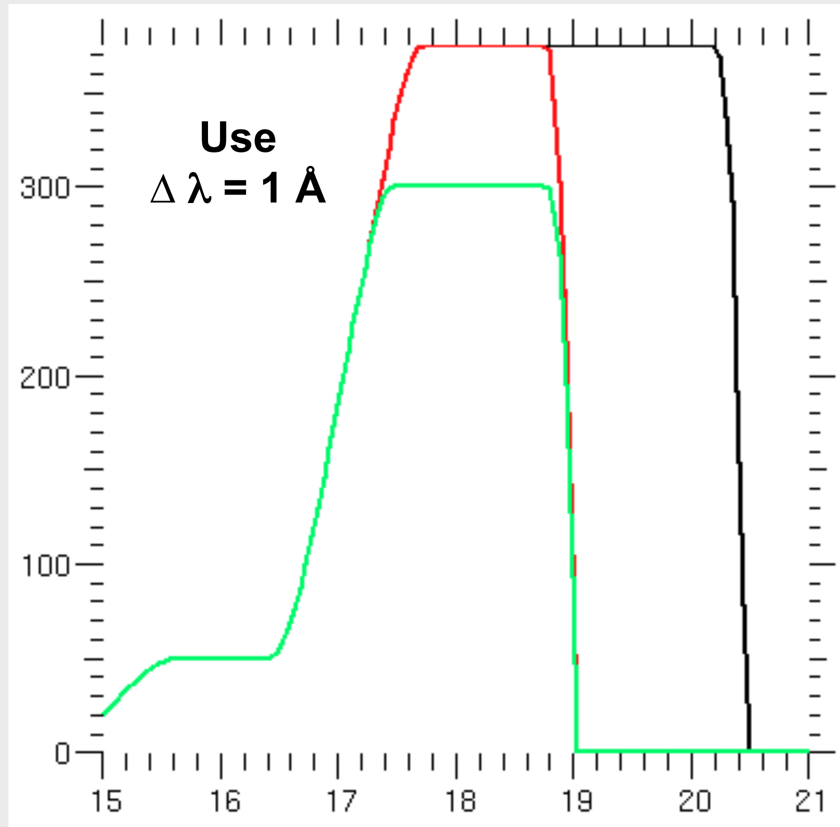
STRATEGY

Ramp up laser power and energy to near ignition-like conditions, while assessing SBS levels and optics damage

Rugby "Walk-Up" to Peak Power and MJ



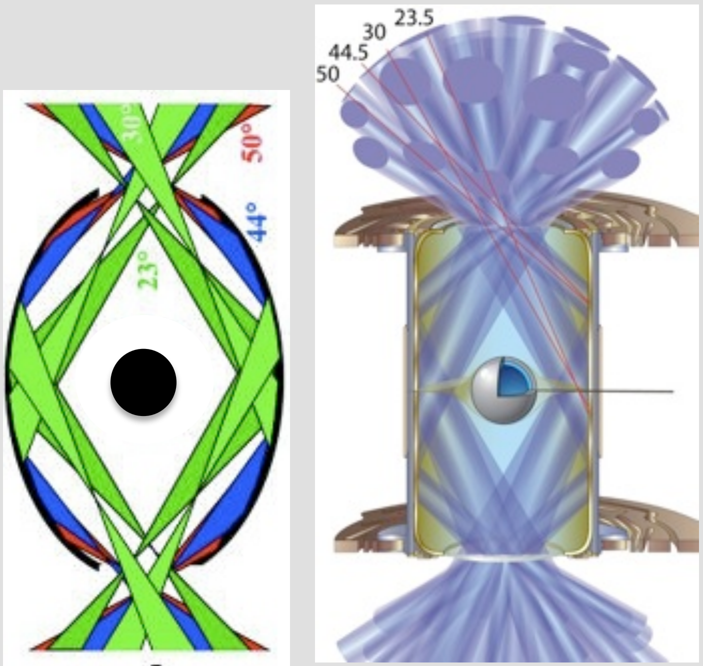
Rugby "Walk-Up" to Peak Power and MJ



We proposed to use one each of 23, 30, 44.5 and 50° quads to look ahead – Run at 375 TW 1.335 ns for 1st shot and full 2.6 ns for 3rd shot

Rugby shaped hohlraum allows more volume over the capsule waist for the same hohlraum wall area

Rugby vs cylindrical hohlraum



Rugby hohlraum part

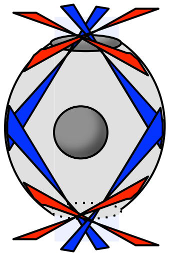
- **Expect rugby to**
  - **Improve inner beam propagation due to lower plasma density around capsule waist**
  - **Less crossbeam transfer required for round implosion**
  - **Possibly reduce backscatter on inner cone**
  - **Risk of increased SBS on outer cone**

First NIF rugby experiments done in March and May, 2013 (N130318, N130502)

P Amendt talk

BENEFITS

Rugby 700 hohlraum was predicted to provide inner beam propagation without need for XBET



- Greater 23° cone capsule clearance (28% larger) than cylinder

  - but inner cone pathlengths are longer

- Simulations show absence of cylinder hohlraum blowoff "bubble" that complicates analysis of inner beam propagation and backscatter

- Less Au M-band (>1.7 keV) fraction is predicted (31% smaller)

Both mainline CEA and LLNL preshot simulations showed nearly round implosions

Rugby hohlraum may present higher outer cone SBS (Brillouin) backscatter due to more obliquity

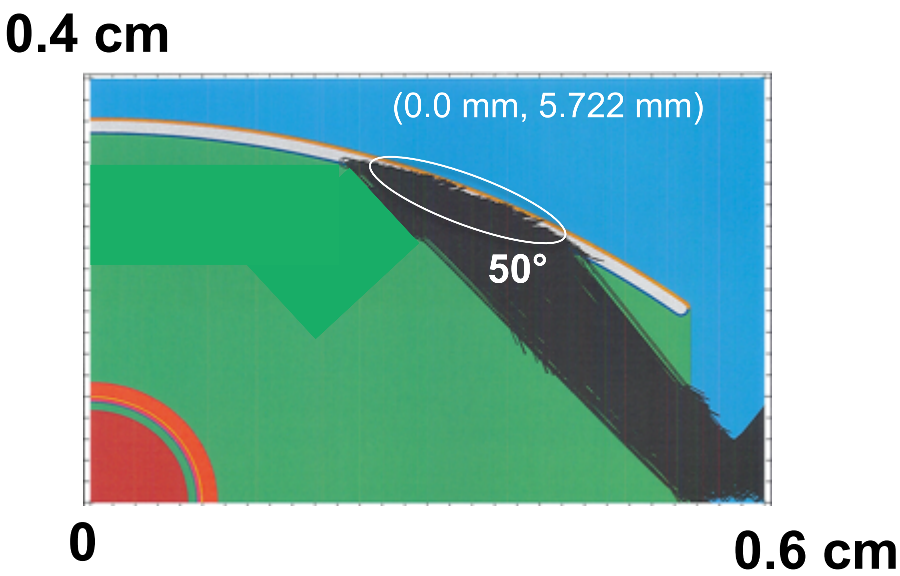
- Outer cone grazing angle leads to less gradient stabilization, longer path length through dense Au and possibly higher SBS

  - but OMEGA vacuum vs gas-filled rugby data showed markedly lower backscatter when hohlraum blowoff is well tamped

  - preshot analysis of SBS showed risk in outer cones

  - "borating" Au could help remedy if SBS is high

  - modifying rugby shape near LEH might help, e.g., "super ellipse"



- Longer laser path lengths for 700-scale rugby

BACKUPS